Fall 2021 Image/Video 1 Report

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I. Introduction

The purpose of this photo was to explore a fluid phenomenon and to become familiar with flow photography. For this image I captured a droplet-surface interaction in a rheoscopic fluid. The physical explanation for this image largely relies on the influence of surface tension. I would like to acknowledge Ike Timko for assisting with the image capturing.

II. Apparatus

To capture this image, a glass mixing bowl was filled with a mixture of metallic acrylic paint, solid-colored acrylic paint, tap water, and dish soap. The only light source in the room was an iPhone XR flashlight which was located to the lower left in the field of the image. A pipette was used to extract a small amount of the mixture from the bowl and slowly dispense it back into the remainder of the mixture. It was determined that the best results occurred when the tip of the pipette was held three inches above the surface of the solution. The drops from the pipette then sat on the surface of the liquid for up to 2 seconds before sinking back into the bowl. These droplets are the pearl-like objects in the photo. Below is a diagram of the physical setup.

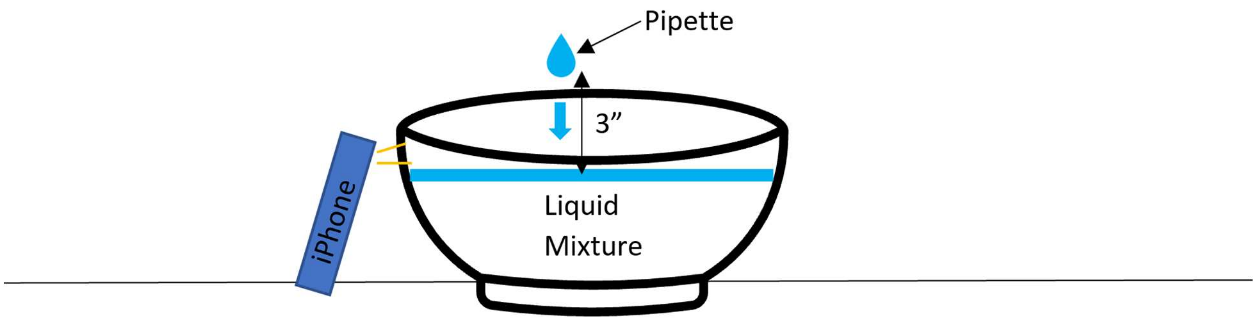

Figure 1: Experiment setup diagram. Note- not to scale.

III. Physics Explanation

There are two main phenomena captured in the image. In the foreground there are pearl-like droplets while in the background, there are waves/ripples from the initial impacts of the pearls. Both phenomena are a result of the effects of surface tension.

The general equation for surface tension is shown in equation (1) below. In equation 1, γ is defined as "the magnitude of the force exerted parallel to the surface of a liquid, F, divided by the length of the line over which the force acts, L" [4,6].

$$\gamma = \frac{F}{L} \tag{1}$$

III.1 Droplets

The pearl-like droplets maintain their spherical shape through the effects of surface tension. Conceptually, surface tension is the tendency of resting liquid surfaces to contract to the minimum surface area possible [3]. Below is a diagram illustrating the molecular level effects of surface tension for a droplet:

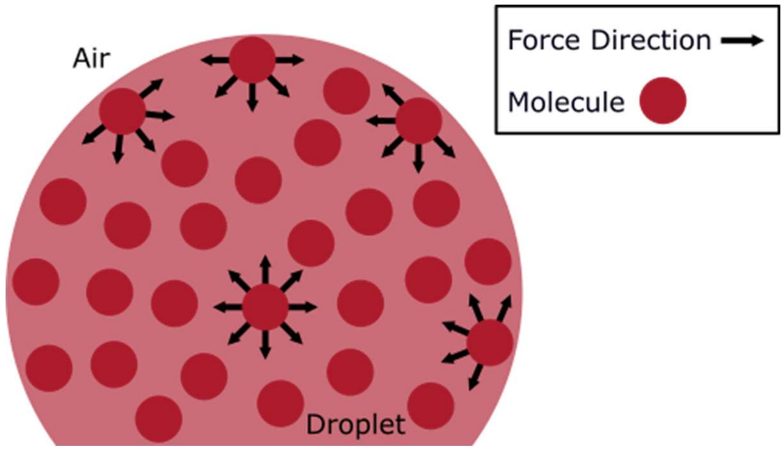

Figure 2: Surface Tension of a droplet. See source [3].

At liquid-air interfaces, like the one in figure 2, the droplet formation results from the cohesive force between the liquid molecules to one another. The cohesive force is greater than the liquid attraction to the air molecules. Therefore, the molecules on the surface of the droplet experience an inward force. This force causes the liquid to contract, forming the familiar spherical shape [1].

The suspected reason the droplets would briefly lie on the surface of the liquid in the bowl before dropping back into the mixture is because the acrylic paint and the water in the bowl separated slightly due to density differences, leaving a thin layer of water on the surface. The mixture was allowed to settle for about 5 minutes before the drops were released and in that time some separation occurred. Once I released the droplets, they would briefly remain buoyant on the thin water layer at the surface of the solution before recombining with the rest of the mixture. Acrylic paint is made with polymers such as plasticizers which make it water-resistant. However, acrylic paint is still porous, so once the droplet was in contact with the thin layer of water it would slowly absorb the water and rejoin the mixture in the bowl once a threshold water absorption was reached [5,9]. This reabsorption was on the order of seconds.

III.2 Capillary Waves

The waves in the background of the image are created by the force of a droplet falling into the bowl from the pipette. This type of wave is known as a capillary wave. A capillary wave is defined as a wave that travels along the phase boundary of a fluid whose dynamics work to restore the surface tension of the liquid [2]. In this image these waves occur at the boundary between the air and rheoscopic liquid, and they are forced by the impact of the droplets on the surface of the liquid. The waves then act as a restoring force for the surface tension on the liquid boundary. In the upper left of the image, you can also see some dispersion of the capillary waves. This dispersion is dictated by [8] and can be described with equation (2) below:

$$\omega^2 = gk + \frac{\gamma k^3}{\rho} \tag{2}$$

Where ω is the angular frequency with units of $[\frac{radians}{second}]$, g is the acceleration due to gravity with units $[\frac{m}{s^2}]$, k is the wave number, ρ is the density of the fluid $[\frac{kg}{m^3}]$, and γ is the surface tension, which can be treated as an isotropic force per unit length with units of $[\frac{N}{m}]$. The surface tension can be computed with equation (1). Since the rheoscopic mixture is denser than water (due to the addition of acrylic paints), we can expect the angular frequency to be smaller than that of a pure water experiment, implying the waves will not move as quickly.

Note: the true fluid properties needed to calculate the dispersion relation are unknown due to the lack of measuring equipment.

IV. Visualization Technique

To capture the details of the fluid movement, a rheoscopic liquid was made. To create the rheoscopic mixture dish soap, acrylic paints and water were combined. The amounts of each are presented in table (1) below.

Component	Amount
Metallic Acrylic Paint	7 mL
Solid-Color Acrylic Paint	15 mL
Liquid Dish Soap	3 mL
Tap Water (room temperature)	2 L

Table 1: Composition of Rheoscopic fluid

Figure 3: The acrylic paints and dish soap that were used to create the rheoscopic mixture.

The solid-color acrylic paint provided the blue color, while the metallic acrylic paint provided reflective particles to help show the motion of the liquid. Without the dish soap, the movements of the liquid were barely visible due to high surface tension. The dish soap acted as a surfactant and reduced the surface tension between the acrylic paint and water, which increased its spreading properties [7] allowing the shimmer in the acrylic paint to easily be tracked by eye.

As for the lighting of the image, I used an iPhone XR light located towards the lower left of the field of view. The iPhone was propped up against the glass bowl and the light was slightly above the surface of the liquid since the liquid was opaque due to the choice of opaque acrylic paints. The rest of the room was pitch black and the camera flash was not utilized.

V. Photographic Technique

This image was captured using a Nikon D3300 DSLR camera with an 18-55mm lens. The exact properties for the image are tabulated below.

Property	**Value**
Shutter Speed	1/400 sec
Focal Length	48mm
ISO	3200
Aperture	f/5.3
Pixels	6000 x 4000

Table 2: Photographic properties.

The lens was about 5 inches from the surface of the liquid, while the pipette was about 3 inches above the surface. I wanted to capture a detailed image of the surface interaction, so I chose to exclude the pipette and the glass bowl in the field of view. I also wanted to zoom in enough to make out the shimmer details of the liquid.

Due to the short duration of the phenomenon, a fast shutter speed and continuous capture were required. The pearls would quickly sink into the mixture, so multiple shots were taken while the pipette continuously released droplets.

Due to the lack of light in the room, a high ISO was necessary for the camera to capture enough light. The image was finalized using Dark Table. The contrast and saturation were increased to make the image more dramatic. The highlights and shadows were also adjusted to make the sheen of the liquid stand out.

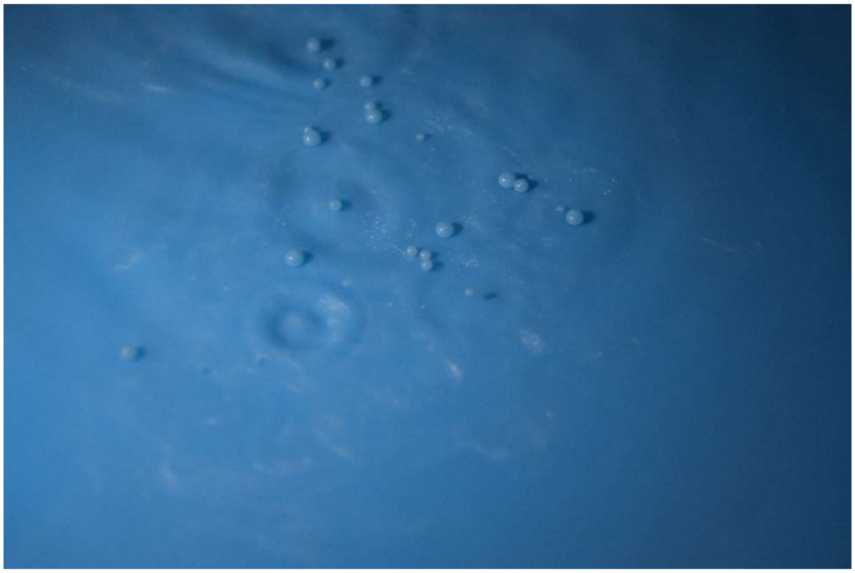

Figure 5: Original image from camera.

Figure 6: Final image after editing.

VI. Conclusion

This image depicts a surreal fluid landscape. The background of the image demonstrates the unique wave interactions caused by the droplets' perturbations while the foreground highlights the droplets themselves. I think the shimmer in the fluid adds to the image's complexity. I'm very happy with how this image turned out, especially the mood of the image. I think it would be interesting to try this experiment again but change the color of the liquid in the pipette. That way the pearls could contrast the surface of the liquid. As for the physics, I would still like to measure the appropriate values to determine the numerical surface tension.

VII. Resources

[1] Berry, M V. *The Molecular Mechanisms of Surface Tension*. H H Wills Physics Laboratory, https://michaelberryphysics.files.wordpress.com/2013/07/berry018.pdf.

[2] “Capillary Wave.” *Encyclopedia Britannica*, Encyclopedia Britannica, Inc., https://www.britannica.com/science/capillary-wave.

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[4] Hodgkins, Leila. “Surface Tension.” *Schoolphysics*, https://www.schoolphysics.co.uk/age16-19/Properties%20of%20matter/Surface%20tension/text/Surface_tension/index.html.

[5] “Solved: Is Acrylic Paint Waterproof?” *Home Logic UK*, https://www.homelogic.co.uk/solved-is-acrylic-paint-waterproof.

[6] “Surface Tension.” *UCSC*, http://scipp.ucsc.edu/~haber/ph5B/bubble.pdf.

[7] “Surfactant.” *Encyclopedia Britannica*, Encyclopedia Britannica, Inc., https://www.britannica.com/science/surfactant.

[8] Thorne, Kip. *Chapter 16: Waves*. University of CalTech, 7 Sept. 2012, http://www.pmaweb.caltech.edu/Courses/ph136/yr2012/1216.1.K.pdf.

[9] Valentin, et al. “Is Acrylic Paint Waterproof?- No, It Isn´t and Here Is Why.” *Craftknights*, 22 Dec. 2020, https://craftknights.com/is-acrylic-paint-waterproof/.